FURROW WATER INTAKE REDUCTION WITH SURGE IRRIGATION OR TRAFFIC COMPACTION

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ABSTRACT

Excessive water intake and related deep percolation losses have not been considered a major limitation for growing season irrigation applications through graded furrows on slowly permeable soils. However, applications of 100 to 200 mm (4 to 8 in.) are common for the first irrigation after primary tillage; and before furrow surface consolidation reduces intake during succeeding applications. Both furrow compaction by wheel traffic and surface consolidation by surge irrigation have potential as relatively low cost methods of reducing intake, thereby reducing percolation losses and conserving irrigation water. Field studies were conducted in the Southern High Plains on a slowly permeable Pullman clay loam (Torrertic Paleustoll) to compare the effects of furrow compaction by wheel traffic and surge flow on irrigation intake during the first irrigation after primary tillage. Where 0.75 m (30 in.) spaced furrows had been tilled to the 200 mm (8 in.) depth; one traffic pass with a 6 mg (13,000 lb) tractor, increased bulk density from about 1.0 to 1.4 mg/m^3 (62 to 87 lb/ft^3). During the first irrigation after primary tillage, the effect of furrow traffic compaction reduced irrigation water intake (application less runoff) by 18 to 27%. Surge flow, without furrow traffic, reduced intake by about the same amount while plant available soil water storage to the 1.8 m (6 ft) depth was reduced by only 5 to 10%.

KEYWORDS. Furrows, Irrigation, Infiltration, Soil compaction, Soil moisture.

INTRODUCTION

Reducing irrigation water use is important for the sustainability of irrigated agriculture on the Southern High Plains. Relatively high energy costs for pumping from the Ogallala Aquifer and reduced well yields from declining groundwater storage have caused an increased interest in reducing irrigation water application. One of the major reasons for high irrigation water use by furrow irrigation, is relatively high water intake at the upper end of the furrow to ensure adequate intake at the lower end of the furrow. This often causes profile drainage loss through deep percolation. The effect is much more pronounced during the first irrigation after primary tillage and on moderately permeable compared with slowly permeable soils.

These high intake rates during the first irrigation are related to loosened surface soil conditions from primary tillage and winter frost action. Musick et al. (1987) reported that preplant irrigation depths of 150 to 250 mm (6 to 10 in.) have been measured with graded furrow application after pre-season primary tillage on the fine textured Pullman clay loam in the Amarillo, Texas, area when the amount of soil water storage needed to wet the 1.8 m (6 ft) soil profile to field capacity is normally less than 100 mm (4 in.). Undersander and Regier (1988) reported average preplant furrow irrigation intake of 237 mm and 466 mm (9.5 and 18.6 in.), respectively, for fall and spring applications on a Sherm silty clay loam near Dumas, Texas. The much higher irrigation application in the spring resulted from high intake associated with unusually high winter precipitation as snow, and multiple freeze-thaw cycles following fall primary tillage. The very high intake occurred in non-wheel track furrows.

Later season applications, after furrow surface consolidation from previous irrigation, are normally about 80 to 120 mm (3.2 to 4.8 in.) on the slowly permeable clay loams. Because of residual soil water storage from the previous irrigated crop plus precipitation storage, applications of 75 to 100 mm (3 to 4 in.) are usually adequate to bring the rooting profile to field capacity during the first spring irrigation.

Trout and Kemper (1983) reported four major management factors that affect irrigation furrow intake:

- Wheel compaction of furrows.
- Surface soil water content.
- Furrow flow rates.
- Intermittent application such as "surge irrigation.

We address the effects of furrow compaction by wheel traffic and surge application. Research in Nebraska, Idaho, Wyoming, and Texas has shown that furrow compaction can reduce intake from 20 to 50% (Eisenhauer et al., 1982; Trout and Kemper, 1983; Fornstrom et al., 1985; Musick et al., 1985; and Musick and Pringle, 1986). Results from these previous studies were summarized by Allen and Musick (1989). Yoder et al. (1989) reported on infiltration and wetting patterns beneath adjacent wheel and non-wheel furrows on a very fine sandy loam in Colorado where there was more infiltration and slightly more lateral movement of irrigation water from non-compacted furrows. Research on the medium to fine textured soils of the Texas Panhandle has shown that furrow traffic compaction can reduce irrigation intake by about 15 to 35% during the first application after primary tillage (Allen and Musick, 1989).

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Surge flow, introduced in Utah by Stringham and Keller (1979), is the intermittent application of irrigation water creating a series of on and off periods (cycles) of constant or variable duration. The surge effect, which results in reduced irrigation intake and can be managed to improve intake distribution with length of run; was reviewed by Stringham (1988). Musick et al. (1987) reported that surge flow reduced irrigation intake by 32% during the first application after primary tillage on a moderately permeable Olton clay loam near Friona, Texas. During succeeding applications after the furrow surface had consolidated, surge reduced intake by an average of 17%, while corn yield was reduced only by 6%. Walker (1984) and Musick and Walker (1987) reported that surge is beneficial for reducing deep percolation losses, even on relatively low intake soils, during the first irrigation after primary tillage.

Schneider (unpublished) evaluated various surge cycle time lengths and furrow inflow rates in comparison with continuous flow irrigation on a Pullman clay loam at Bushland, Texas. With equal numbers of irrigation applications, surge resulted in 20 to 25% less irrigation intake and only 4% lower grain yields in one year. In the second year, yield was not reduced by surge. The applied irrigation water use efficiency (grain yield/water applied) for surge irrigated grain sorghum ranged from 19 to 26% higher than for continuous flow irrigation.

Our objectives were to:

- Directly compare the effectiveness of surge flow and controlled furrow wheel traffic on reducing excessive furrow intake during the first irrigation after primary tillage.
- Determine the effects of these treatments on irrigation intake for succeeding irrigations, after surface soil consolidation from the first irrigation, on a fine-textured clay loam.

PROCEDURE

The study was conducted in 1989 and 1990 at Bushland, Texas, on 400-m (1320-ft) length furrows, spaced 0.75 m (30 in.) apart with a 0.15% slope. The soil, a fine textured and slowly permeable Pullman clay loam (Torrertic Paleustoll), was described by Unger and Pringle (1981). This soil has a plant available water holding capacity of 240 mm (9.4 in.) to the 1.8 m (6 ft) depth.

Soil preparation during the winter was accomplished by disking to incorporate sorghum residue from the previous crop, followed by sweep undercutting 200 mm (8 in.) deep for soil loosening. Furrows were formed in the spring and bed-furrows were smoothed with a rolling cultivator before irrigation applications using six-row equipment. On compaction treatments, one furrow compaction pass was made with a 6000-kg (13,000-lb) tractor immediately after bed-furrow cultivation. This size tractor is typically used for six-row equipment.

Furrow treatments are listed as follows:

T-1 No furrow traffic (check)
T-2 Furrow traffic
T-3 Surge

Plots were 4.5 m (15 ft) or 6 furrows wide by 400 m (1320 ft) long. Plot borders were established at the center of each six-row furrower pass so that the three center furrows of each plot received no wheel traffic on non-compacted treatments. Four adjacent T-3 surge plots were located in the center of the research area. The T-1 and T-2 treatments were alternated on each side of the surge area, providing four replications for all treatments. Irrigation water was applied through gated pipe and measured with a propeller meter. Individual furrow inflow rates were adjusted to the desired application rate. Individually calibrated portable "H" flumes, equipped with water level recorders, were used to measure furrow runoff from the three center furrows of each treatment. For surge applications, a commercially available controller was used. A commercially available "digitizing tablet" PC computer interface option was used to read flume runoff hydrographs. Irrigation dates were 10 October 1989; and 12 June and 21 August in 1990. After the 1989 preplant irrigation test, wheat was seeded to deplete soil water during the winter and early spring. The wheat was removed by tillage in early spring and new bed-furrows were formed for the 1990 preplant irrigation test, which was followed by planting grain sorghum to deplete soil water before the postplant irrigation test.

In 1989, two furrow inflow rates [38 and 60 L/min (10 and 16 gal/min)] each were used on T-1 and T-2 continuous flow treatments; and 90 L/min (24 gal/min) was used for T-3. The two flow rates, for continuous flow, bracket the typical range of flow rates used for 400 m (1320 ft) length furrows with low grades (0.15 to 0.5%) on this soil. In 1990, furrow inflow rates were set at 60, 45, and 76 L/min (16, 12, and 20 gal/min), respectively, for T-1, T-2, and T-3 during the preplant application. For the postplant application, flowrates were 53, 45, and 76 L/min (14, 12, and 20 gal/min), respectively, for T-1, T-2, and T-3.

During the advance phase, surge half-cycles (furrow flow on-times) were progressively increased. Four half-cycles of 50, 72, 101, and 137 min were used during the advance phase, followed by a 80 min half-cycle during the infiltration phase. For the preplant application in 1990 with relatively dry soil, six half-cycles of 40, 48, 60, 74, 90, and 108 min were used during the advance phase, followed by two 60 min half-cycles during the infiltration phase. For the postplant application after furrow surface consolidation, five advance phase half-cycles of 36, 48, 60, 72, and 84 min were used followed by 60 min infiltration half-cycles. At the time of the preplant irrigation in 1990, a flowing-furrow infiltrometer was used for 8 h tests on blocked 4.6 m (15 ft) sections of T-1 and T-2 furrow treatments.

Soil water contents were determined gravimetrically by 0.3 m (1 ft) increments to the 1.8 m (6 ft) depth before and after irrigations at 30, 200, 300, and 365 m (100, 650, 1000, and 1200 ft) sites along the 400 m (1320 ft) length of run. A core sampler was used to obtain soil bulk densities in furrows by 100 mm (4 in.) depth increments to 400 mm (16 in.) deep at the 30 and 200 m (100 and 650 ft) sites before the irrigation applications in 1989. The bulk density of the 75-100 mm (3-4 in.) of loose soil in the non-traffic furrow was determined by careful volumetric sampling using 230 cm^3 (14 $in.^3$) volume soil cans with four replications. Cone index values for soil strength were determined at the same time with a tractor mounted hydraulic penetrometer. The penetrometer tip size was 20.27 mm (0.798 in.) diameter, and the shape and rate of tip travel conformed to ASAE Standard 5313.2 for soil cone penetrometers (ASAE, 1989).

Results and Discussion

Furrow Bulk Density

Furrow bulk density data, obtained before the preplant irrigation in 1989, are presented in Table 1. The soil in nontraffic (T-1) furrows was relatively loose to the 100 mm (4 in.) depth. This resulted from the fluffing action of a rolling cultivator and is reflected by the low density of 0.98 mg/m^3 (61.1 lb/ft^3), compared with a much higher density of 1.42 mg/m^3 (88.6 lb/ft^3 for the traffic compacted furrows at the same depth. The tillage depth of 200 mm (8 in.) is clearly indicated by the rather abrupt density change from 1.12 to 1.4 mg/m^3 (70 to 87.4 lb/ft^3) on T-1. The bulk density of 1.4 to 1.5 mg/m^3 (87.4 to 93.6 lb/ft^3), below the 200 mm (8 in.) depth, in the non-compacted T-1 treatment is typical of undisturbed densities at that depth in this soil (Allen and Musick, 1989). There was a slight traffic compaction effect below the 200 mm (8 in.) tillage depth on T-2.

Soil bulk density measurement, with 100 mm (4 in.) length cores, may not permit the detection of relatively thin layers (pans) of higher density that may be only about 25 to 50 mm (1 to 2 in.) thick. This condition is dramatically illustrated by the cone index plot in figure 1 that illustrates the occurrence of a distinct layer with higher soil strength between 50 and 100 mm (2 to 4 in.) below the surface of the compacted furrow in 1989. Soil bulk density, before the preplant irrigation in 1990, was essentially the same as in 1989. Soil water contents to 0.3 m (1 ft) deep were similar in both years (40 to 50% of field capacity) at the time of furrow compaction by tractor traffic.

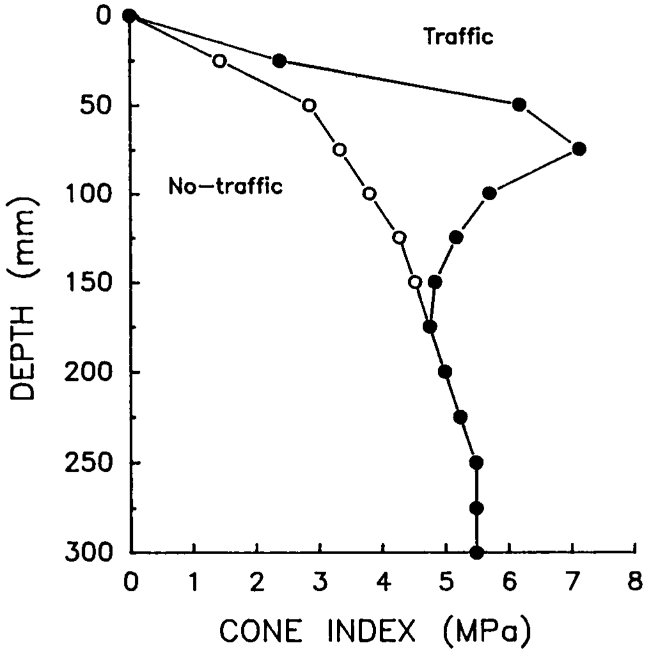

Figure 1–Cone index with depth at time of preplant irrigation, 1989. (25 mm = 1 in., 1 MPa = 145 psi)

Water Application and Intake

Total water application, runoff, and intake data are presented in Tables 2 and 3. In 1989, after a delay by a relatively wet summer, soil profile water content remained at 80% of field capacity to 1.8 m (6 ft) deep. Even with the relatively wet soil profile, the 200 mm (8 in.) tillage layer depth was relatively dry and irrigation intake of 165 mm (6.5 in.) for T-1 was rather high during the preplant irrigation for wheat. Thus, intake exceeded available storage capacity to 1.8 m (6 ft) deep by about 120 mm (4.9 in.). The excess intake was mostly lost to deep percolation beneath the rooting zone. This case of a relatively dry tilled layer overlying moist soil is representative of conditions when producers may elect to apply a preplant irrigation to wet the surface and ensure crop emergence, even with the risk of substantial deep percolation losses (Allen and Musick, 1990). This soil has a very high, initial intake rate while shrinkage crack volume is being filled. This initial high rate is followed be a rapid decline to a low basic intake rate [less than about 5.0 mm/h (0.2 in./h)] as measured by flowing furrow infiltrometer.

TABLE 1. Soil bulk density beneath the furrow before irrigation application, 1989, Bushland, TX

Depth	Bulk Density T-1 (No-Traffic)	Bulk Density T-2 (Traffic)
mm (in.)	mg / m^3 (lb / ft^3)	
0-100 (0-4)	0.98 (61.1)	1.42 (88.6)
100-200 (4-8)	1.12 (69.9)	1.50 (93.6)
200-300 (8-12)	1.40 (87.4)	1.50 (93.6)
300-400 (12-16)	1.50 (93.6)	1.60 (99.8)

TABLE 2. Irrigation application, intake, advance time, and storage, Bushland, TX (1989-90) (metric units)

Treatment	Furrow Inflow (L/min)	App. (mm)	Intake (mm)	Intake % of Check (%)	Advance / Set Time (h)	Stor. (mm)	Stor. Eff. (%)
1989							
T-1 Check	38	185	170	100	20.6 / 24.0	41	24
	60	183	165	100	12.3 / 15.3	41	25
T-2 Traffic	38	180	140	82	13.5 / 24.0	44	31
	60	183	135	82	8.1 / 15.3	44	33
T-3 Surge	90	137	132	79	12.0 / 14.7	47	36
1990							
Preplant Irrigation							
T-1 Check	60	237	197	100	14 / 18	144	73
T-2 Traffic	45	161	144	73	17 / 20	116	81
T-3 Surge	76	158	146	74	16 / 20	130	89
Postplant Irrigation							
T-1 Check	53	145	135	100	11 / 14	171	79
T-2 Traffic	45	124	112	83	11.5 / 14	147	76
T-3 Surge	76	102	99	74	10 / 12	140	71

TABLE 3. Irrigation application, intake, advance time, and storage, Bushland, TX (1989-90) (English units)

Treatment	Furrow Inflow	App.	Intake	Intake % of Check	Advance / Set Time	Stor.	Stor. Eff.
	(gal/min)	(in.)	(in.)	(%)	(h)	(mm)	(%)
1989							
T-1 Check	10	7.3	6.7	100	20.6 / 24.0	1.6	24
	16	7.2	6.5	100	12.3 / 15.3	1.6	25
T-2 Traffic	10	7.3	5.5	82	13.5 / 24.0	1.7	31
	16	7.2	5.3	82	8.1 / 15.3	1.7	33
T-3 Surge	24	5.4	5.2	79	12.0 / 14.7	1.8	36
1990							
Preplant Irrigation							
T-1 Check	16	9.3	7.8	100	14 / 18	5.7	73
T-2 Traffic	12	6.3	5.7	73	17 / 20	4.6	81
T-3 Surge	20	6.2	5.7	74	16 / 20	5.1	89
Postplant Irrigation							
T-1 Check	14	5.4	4.8	100	11 / 14	6.7	79
T-2 Traffic	12	4.5	4.1	86	11.5 / 14	5.8	76
T-3 Surge	20	3.9	3.8	79	10 / 12	5.5	71

The 1989 test of 60 L/min (16 gal/min) and 38 L/min (10 gal/min) flow rates indicated that there was only a slight flow rate effect on total intake when application and total runoff amounts were similar (Tables 2 and 3). However, the higher flow rate on both T-1 and T-2 reduced advance times by about 40%. Since flow rate did not affect intake on continuous flow treatments in 1989, only one flowrate was used for continuous flow application tests in 1990.

The furrow traffic and surge treatments noticeably reduced intake by 18 to 27% compared with the check in both years. The intake reduction effects of furrow traffic and surge were similar. During the postplant application in 1990, the intake for all treatments ranged from 60 to 70% of the preplant application as a result of furrow surface soil consolidation and sealing. The T-2 treatment had slightly higher intake than did T-3.

The results of a flowing furrow infiltrometer test on traffic and check furrows, at the time of the preplant irrigation in 1990, is presented in figure 2. The greatest difference in intake rate between traffic and check furrows occurred during the first 2 h (fig. 2). Although the difference in intake rate after 2 h appears to be rather small, the infiltration rate of the check [10-12 mm/h (0.4-0.5 in./h)] was nearly double that of T-2 furrows at 6 mm/h (0.24 in./h). The difference in cumulative intake was substantial. After 4 h, cumulative intake for the check treatment was 150 mm (5.9 in.) or 61% greater than for T-2 at 92 mm (3.6 in.). After 8 h, cumulative intake increased to 194 mm (7.6 in.) for the check treatment and 116 mm (4.6 in.) for T-2.

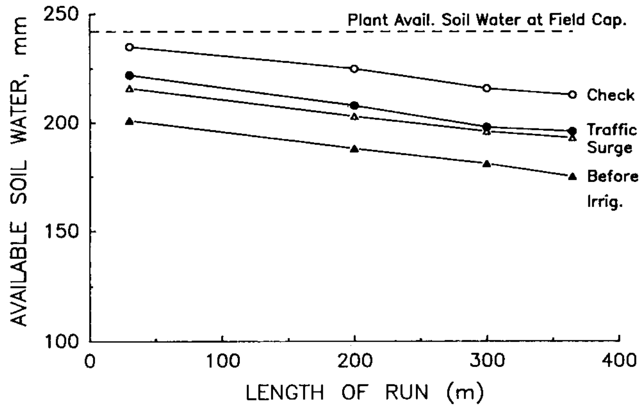

Figure 3–Plant available soil water contents to 1.8 m (6 ft) depth along length of furrow run before and after preplant irrigation for wheat, 1989. (25 mm = 1 in., 1 m = 3.28 ft)

Soil Water Storage

The plant available soil water contents to the 1.8 m (6 ft) depth, before and after irrigation, are presented for the 1989 preplant irrigation for wheat in figure 3, and for the 1990 preplant and postplant irrigations for sorghum in figures 4 and 5. The declines in soil water content, as distance increased along the length of run, are about the same both before and after irrigation applications, and are similar for all treatments.

At the time of the preplant irrigation in 1989, the capacity for increased plant available soil water storage was only about 45 mm (1.8 in.). Thus, with irrigation intake ranging from 130 to 170 mm (5.2 to 6.7 in.), the resulting soil water storage efficiencies (storage

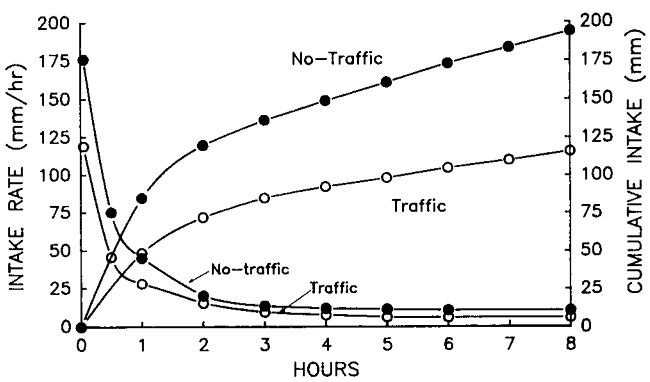

Figure 2–Intake rate and cumulative intake vs. time during first irrigation after primary tillage as measured by flowing furrow infiltrometer, 1990. (25 mm = 1 in.)

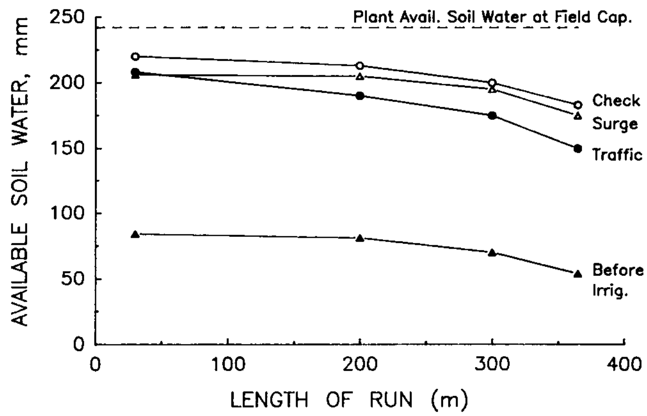

Figure 4–Plant available soil water content to 1.8 m (6 ft) depth along length of furrow run before and after preplant irrigation, 1990. (25 mm = 1 in., 1 m = 3.28 ft)

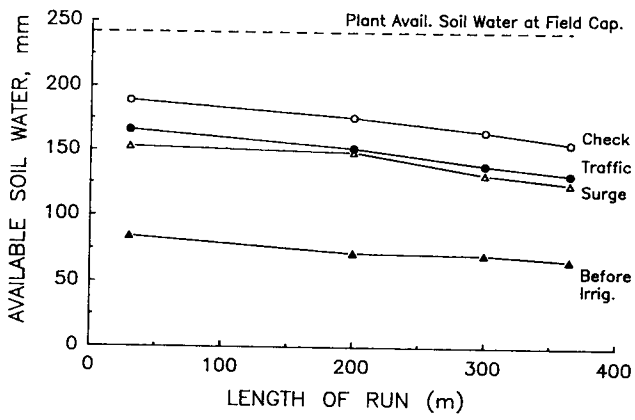

Figure 5–Plant available soil water content to 1.8 m (6 ft) depth along length of furrow run before and after second irrigation of sorghum, 1990. (25 mm = 1 in., 1 m = 3.28 ft)

increase/intake) ranged from only 24 to 36% (Tables 2 and 3). This very high intake, from three to four times greater than the storage capacity, indicates the occurrence of preferential flow and a resulting loss to deep percolation as evidenced in figure 6.

At the time of the preplant irrigation in 1990, plant available profile water storage was about 30% of field capacity because of depletion by wheat prior to being removed in early spring. This condition was a major contrast to the relatively wet lower soil profile before the 1989 preplant irrigation. The T-2 treatment had slightly lower soil water storage than the T-3 or check treatments which had similar storage after the preplant irrigation in 1990. This gain in storage from irrigation averaged 130 mm (5.1 in.) with storage efficiencies in the 73 to 89% range. The storage efficiency was slightly greater for surge irrigation during preplant applications in both years compared with the check and furrow traffic treatments.

The soil water contents plotted in figure 6 illustrate the extent of soil profile wetting by preplant irrigations in 1989 and 1990. There is very little difference in storage pattern with depth among furrow treatments. The major difference in profile storage gained from the preplant irrigations in 1989 and 1990 is evident. Deep percolation from the 1989 preplant irrigation is apparent when very little profile storage room was available before the irrigation was applied.

For the postplant application in 1990, the plant available soil water content was at about 30% of field capacity and the sorghum was showing visible stress. The increase in soil water storage was about 25% greater for the check treatment compared with T-2 and T-3 treatments. This indicates that both furrow compaction and surge can have adverse effects on later season irrigation intake and storage on a fine textured soil. These results are similar to that experienced by Manges and Hooker (1984), Walker (1984), and Musick and Walker (1987) when surge flow was helpful in reducing excessive irrigation intake during the first application after primary tillage, but could be detrimental by reducing later season irrigation intake more than desired.

These results indicate that either furrow compaction by traffic or surge flow can be used to reduce excessive furrow irrigation intake and related deep percolation losses during the first irrigation after primary tillage. Furrow traffic does offer the irrigator, who does not have a surge flow controller, the opportunity to reduce excessive intake. After the preplant irrigation, the effect of traffic compaction can be removed, if needed, by furrow ripping just before the second irrigation (Allen and Musick, 1989). The loosening effect of ripping will usually last through the remainder of the crop season. Thus normal water intake, after furrow surface consolidation, can be maintained without increasing the number of irrigation applications.

These results and previous research (Musick et al., 1981) confirm that the density of the tillage layer to about 0-200 mm (0-8 in.) deep has a major controlling effect on intake with this soil. Musick et al. (1981) found that when one-time deep moldboard plowing was performed to the 0.4, 0.6, and 0.8 m (16, 24, and 32 in.) depth to establish a differential soil profile permeability, later residual tests in succeeding years indicated that periodic loosening of the 0-200 mm (0-8 in.) depth by tillage was necessary to maintain a continuing effect on water intake.

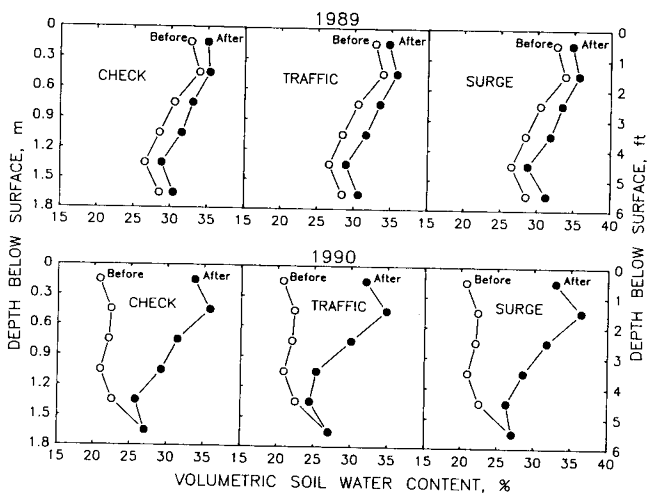

Figure 6–Volumetric soil water content with depth before and after preplant irrigation at midpoint of furrow length [200 m (660 ft)], 1989 and 1990. (1 m = 3.28 ft)

Conclusions

Furrow compaction by tractor traffic and surge flow both reduced water intake on a fine-textured clay loam during graded furrow irrigation. An intake reduction of about 20 to 25% occurred when the soil surface was loose after primary tillage. After surface soil consolidation from previous irrigations and rainfall, the effects continued during the later season irrigation of grain sorghum by reducing the intake from 15 to 20%. When irrigation intake is excessive relative to storage capacity, the treatments tested are effective in reducing loss to deep percolation beneath the root zone. However, continued use of surge may reduce intake below acceptable levels after the first application. Furrow flow rate had a negligible effect on irrigation intake. The tillage layer density to about 200 mm (8 in.) deep has a major controlling effect on intake with this soil.

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